COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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Mad River Station of Ohio Edison Company, Springfield, Ohio

Mechanical-Drive Turbines for Power House Auxiliaries

Evaluation of Proposals for Power Equipment

How to Use Laboratory Tests in Judging Coal Values

Fabrication of Boiler Drums

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VOLUME ELEVEN NUMBER FOUR

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FOR OCTOBER 1939

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DEPARTMENTS

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EDITORIAL

A Novel Power Station Design

The number of new power stations constructed during the last few years has been small compared with the new installations that are housed in existing buildings. Hence, to use automotive parlance, there are many 1936–1939 chassis with 1915–1925 bodies. Unlike many other fields, streamlining does not appear to have taken hold of the power plant field, except as applied to certain individual pieces of equipment. However, among the new stations that have been built during recent years there are several of semi-outdoor construction; in general, the boiler rooms and turbine rooms are not separated by walls; and the buildings are taller in order to accommodate higher boilers, heat recovery, draft and dust-arresting equipment.

Distinctly novel in appearance is the new high-pressure Ottawa Street Station of the City of Lansing, Michigan, which has lately been completed. Located in the heart of the city, its external contour resembles a sixteen-story office building of setback design. There are no stacks visible, although a very short one is concealed within the uppermost walls, and the color scheme of the brick exterior symbolizes the combustion of coal. It represents a rare adaptation of architectural features to modern station requirements.

This plant will invoke widespread attention and may set a precedent for new power stations located within metropolitan areas.

Expediting Deliveries

The present upward swing in business activity has been ascribed to various causes, including conditions in Europe, the prospect of foreign orders and increased markets in Latin America, depleted inventories resulting from hand-to-mouth buying over a considerable period, and a lull in the Government's attitude toward business. The extent to which any one of these factors may be responsible is a debatable question for the economist, although it is probable that all have contributed, plus, perhaps, an optimism tempered with caution. The fact remains that industrial production is increasing, as shown by various indices, particularly those pertaining to the durable goods industries and steel production which so far concern mostly domestic demand.

As might be expected, this situation is reflected in increased power demand. The electric utility load has attained new peaks and further capacity is being sought in several localities. Also, many industrial plants are installing additional power facilities and others are considering them in anticipation of further increases in production demands. Under such conditions early deliveries of power plant equipment are in many cases being sought.

Where there is a desire to secure additional capacity quickly, it would be wise, in view of the considerable interval necessary between the inception of a project and its completion, if purchasers were to be content with consolidating the gains attained through the advances in practice and experience with certain accepted designs over the last few years, without attempting at this time to press further into untried realms. By doing so, they would not impose an added burden on designing engineers, reasonable deliveries could be expected and performance would be assured. Obviously, there will be exceptional cases in which departures from such practice may be warranted, particularly where the time element is of less importance than attaining a given objective.

Aside from the engineering and manufacturing facilities involved, the proper preparation of specifications and proposals would be expedited. As Mr. Clark points out in his article in this issue, the number of alternate proposals requested should be kept to a minimum and their careful preparation simplifies the subsequent work of choosing the equipment.

Fluidity of Coal Ash Slags

Additional light on the relation between the fluidity of coal ash slags and their chemical compositions was contained in a paper by P. Nicholls and W. T. Reid at the Joint Fuels Meeting of the A. S. M. E. and A. I. M. E., held early this month in Columbus, Ohio. This paper reported the results of investigations conducted by the authors at the U. S. Bureau of Mines on the viscosities of such slags at different temperatures, and supplements previous studies already reported. Although the data are still somewhat limited, diagrams were offered which permit reasonably accurate predictions within the range explored.

It would appear that the chief value of these determinations pertains to the flow in slagging-bottom furnaces. For them to be helpful in predicting clinkering and the fusing of fly ash it would be necessary to have a complete history of the coal being fired from day to day, or from hour to hour. It is well known that, due to the process by which coal was formed through the ages, the quantity and composition of the ash content vary within a given seam and mine, and with different carloads from the same working. Also, the mixing of two coals may cause the ash characteristics of the mixture to differ greatly from those of either component.

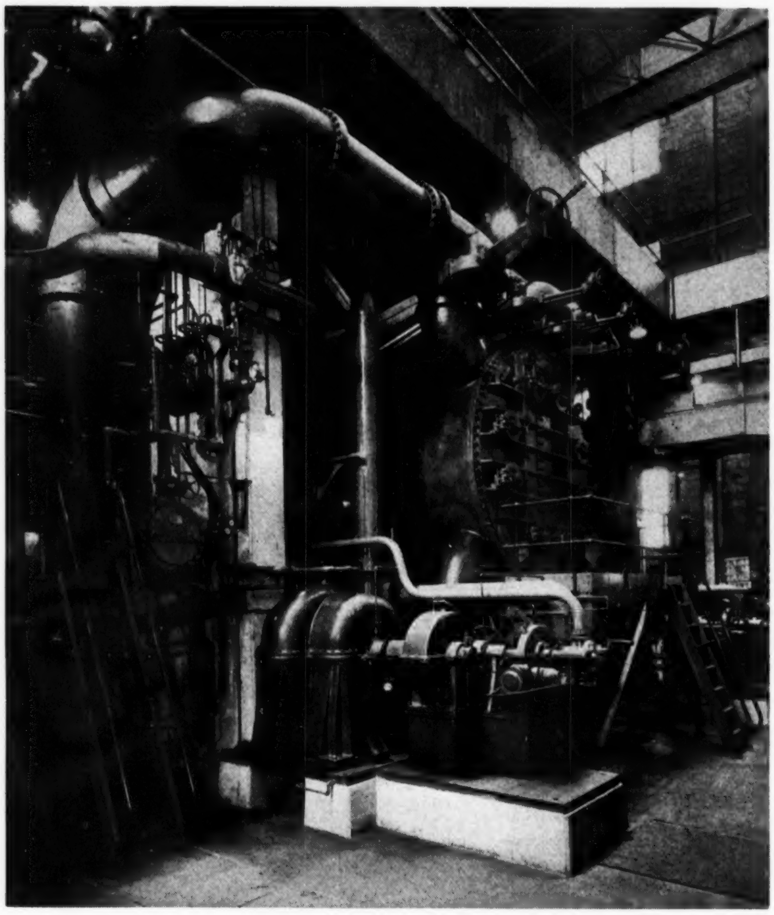
Thus, a coal that is supposed to have a high ash-fusion temperature may at times produce troublesome slagging conditions in the boiler, because of certain fractions in the ash which have a lower fusing temperature and cause the particles to stick together or to adhere to the heating surfaces. Such cases are not uncommon.

Laboratory investigations, such as those made by Messrs. Nicholls and Reid, are most important, and deserve encouragement; but how to make the results applicable and of practical value to the boiler operator and coal purchaser without knowing the complete history of all the coal fired is still a problem.

Mechanical-Drive Turbines for Power House Auxiliaries

By W. SCHMID
Westinghouse Elec. & Mfg. Co.

The author presents the case for turbine drive of auxiliaries from the standpoints of speed control, advantageous heat balance and independence of continuous or outside electrical supply. Features of design and proper foundations for such units are discussed.



Turbine and reduction gear driving circulating pump for large surface condenser; inlet pressure 270 lb gage, exhaust pressure 3 lb gage, turbine speed 3978 rpm, pump speed 345 rpm

IF WE survey the design of any modern power house and its auxiliary drives, it will be found that:

1. The auxiliary apparatus specified is in general rotary and operates at speeds of about 500 to 3600 rpm.
2. While the majority of the applications require a fixed speed, there are certain drives that operate over a narrow range of speeds and some that require a very wide range to fulfill their functions efficiently.
3. The drives should, if possible, be independent of any outside source of power.
4. Proper heat balance can advantageously utilize exhaust steam for feed heating which must be free from oil.
5. The drives should be relatively efficient and of such design that they maintain this efficiency with a minimum of attention over a long period of time.
6. Maintenance of the drives should be low and their design such that they may be dismantled readily for inspection and repair.
7. The design of the drives should be such that the steam and exhaust pipes may be small so as to reduce first cost of piping and insulation, reduce maintenance and obtain maximum flexibility in small space.
8. The drives should be compact not only to save space but to reduce cost of foundations.

The small steam turbine fulfills all these requirements. Let us examine these simple steam-driven prime movers to determine why this type of apparatus is so well suited for this service.

As for speed requirements, no auxiliary drive can equal it. While inherently it is a high-speed piece of apparatus it can readily be adapted to operate over a very wide range of speeds. Standardized designs can be obtained for any speed from about 1000 to 5000 rpm, and turbines can be designed for speeds in excess of this but these are seldom required except for special service. For speeds less than 1000 rpm a gear should be used. Except for such units that are used only occasionally, it will generally be found advantageous to use geared units for auxiliaries requiring speeds up to about 1500 rpm, or even slightly higher, depending upon the operating conditions and the rating.

The boiler feed pump, the forced- and induced-draft fans and the stoker require variable-speed drives. No drive offers such a simple or flexible speed control as the turbine. The speed of the first three mentioned drives can easily be maintained automatically by means of simple valves in the steam lines leading to the drives or by means of regulators actuating their steam admission valves. For manual control, speed changers for narrow change in speed and wide-range governors for greater ranges up to about 3 to 1 can be obtained. These

mechanisms are simple in design and require exceedingly little if any maintenance.

It is essential that the operation of the auxiliaries be independent of outside power. Often emphasis is laid on the necessity of keeping the factory, or whatever the power house is serving, supplied with a continuous source of power. Frequently a concern maintains a power house to assure this continuity. It is therefore only proper that the auxiliaries and their drives be given careful consideration as the chain is no stronger than its weakest link, and just one auxiliary if lost at an unfortunate moment may be that link.

Heat Balance Arrangements

Proper heat balance can be obtained by bleeding of the main turbine or by using exhaust steam from the auxiliaries. If bleeding is employed, a proper balance may be obtained through these means. If bleeding is not employed, the balance may be obtained by driving one or more of the auxiliaries as required by both a motor and a turbine and dividing the load between them so as to obtain the required amount of steam. Since the steam path of a turbine requires no lubrication its exhaust is well suited for feed heating or for process work.

In order to obtain a satisfactory heat balance and performance not only at the start but to maintain this over a long period of time, it is essential that the design of the auxiliary drives be such that their efficiency is maintained at a fairly constant level without adjustments that require special attention or skill. The turbine is inherently such a piece of apparatus if it is properly designed. Most turbines driving auxiliaries have a single governor valve. Some are equipped with hand-operated nozzle-control valves to permit them to develop full power at reduced steam inlet pressure or increased exhaust pressure, or to operate more efficiently at partial loads or reduced speeds. When such valves are furnished care should be taken to use them properly; otherwise, a loss in efficiency may result. Since the basic efficiency of these turbines is determined by the design of their blades and nozzles, the purchaser should carefully consider the skill and design experience of the builder.

If the steam-driven apparatus supplies too much exhaust steam, it should be remembered that the higher speed turbines with gears are considerably more efficient than low-speed direct-connected units. Gears for this type of service have been developed so that they are exceedingly reliable and quiet in operation. Where economy is required this type of apparatus is an attractive investment.

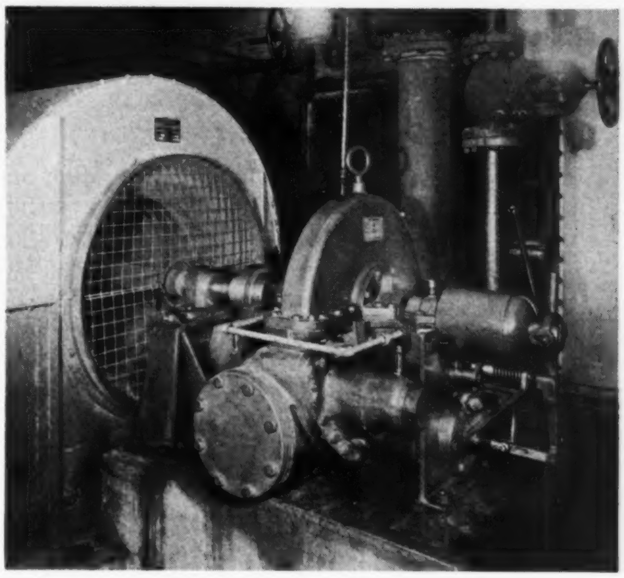
The modern small turbine is designed so that it can easily be dismantled for inspection. If properly designed for the operating conditions imposed upon it, the maintenance of this type of prime mover is low.

Low maintenance is, however, dependent not only on proper design and operation but also on correct installation. In order to maintain proper alignment it is essential that the foundations be adequate and that the turbine be relieved of loads imposed by either the steam inlet or exhaust piping. These should be arranged so as to permit free expansion and the weight of the pipe should be carried on suitable supports. If these precautions are observed alignment of the equipment should be maintained readily.

It might be well to add a few words regarding the functions of a bedplate. A bedplate without a suitable foundation is useless. If it were built rigidily enough to maintain alignment without such a support, it would then cease to be a bedplate and would be a foundation. The function of a bedplate is to support the various pieces of apparatus mounted upon it and maintain their correct relative positions with one another when and only when it is properly mounted on a suitably rigid foundation. It is important to keep this in mind when erecting this type of apparatus and to align all couplings properly before grouting the bedplate to the foundation.

Steam Turbine Is Adapted to Changing Steam Conditions

In the operation of any power house, conditions sometimes arise which require that the auxiliaries carry the necessary loads at reduced inlet steam pressure or increased exhaust pressure. The steam turbine can readily be adapted to meet these conditions. However, it should be kept in mind that if the usual conditions are too far removed from normal, trouble may be experienced at normal conditions. By use of hand valves the performance at normal conditions need not suffer but it must be



Turbine driving forced-draft fan; inlet pressure 100 lb, exhaust pressure 15 lb, speed 1380 rpm

remembered that the governor valve of a single-valve turbine must be made large enough to pass the greater steam volume under the adverse conditions and this may cause the valve to be too near to its seat under normal operation. This may result in hunting or unstable governing. To avoid such a condition, it is desirable to refrain from asking the builder to meet adverse conditions except those that are apt to be experienced during normal conditions, and if possible full capacity should not be called for with both low steam inlet pressure and high exhaust pressure. If the turbine drives an auxiliary whose load can be reduced during such a period, it is well to do so and figure on this when preparing the specifications.

Evaluation of Proposals for Power Equipment

By FRANK S. CLARK
Consulting Engineer
Stone & Webster Engineering Corp.

The author reviews briefly what should be covered by the specifications, the extent to which it is reasonable to expect proposals to include details, the relative importance of various factors and the procedure in comparing the merits of equipment offered with the prices quoted. In view of the complications involved in modern power plant design, it is urged that sufficient time be allowed for the careful preparation of proposals to the end that proper evaluation may be possible.

THE selection of equipment for the generation and utilization of steam and electric power is a procedure totally different from that of choosing the furnisher of such materials as steel, cement or brick. These latter involve no questions of efficiency and reliability of operation, features of design and probable cost of maintenance and can therefore be selected primarily on the basis of the price quoted. With the former, the first cost, while always of prime importance, does not always indicate the cheapest or most economical apparatus. The evaluation of proposals for the furnishing of equipment, therefore, is a process requiring a high degree of technical and practical knowledge both of the equipment itself and of the performance that is expected of it.

A first approach to the problem is a careful study to determine the needs of the situation in order that the number of alternate proposals may be kept to a minimum. This implies that, after obtaining preliminary or approximate data from a manufacturer, the engineer should be able to evaluate the different possibilities open to him and eliminate all but one or at most two or three. This avoids the time and expense to a manufacturer of preparing a number of complete proposals covering the same situation, and a like amount of effort and expense in their analyses by the engineers. On the other hand, the manufacturer can accomplish the same results by determining how he can meet the requirements with his equipment and limit his proposals to the best he has to offer.

Proper Specifications Important

The specification is the prelude to a proposal and the data and requirements it contains form the basis on which the manufacturer determines the design characteristics, efficiencies and price asked for the equipment he proposes to furnish. A carefully prepared specification, therefore, can and does simplify the subsequent work of choosing, on the part of the consulting engineer or purchaser, between the proposals submitted. A specification, in order to meet these requirements, should include the following:

1. A statement of conditions attending the delivery and erection of the equipment which, while not pertaining to design or manufacture, would affect its cost. Among such items would be included delivery facilities at the site, availability of crane for unloading and erection, responsibility for the protection of equipment until it is in commercial operation, furnishing of labor and superintendence of erection.
2. A statement of the equipment to be furnished, giving desired capacities and other information necessary to the making of a proposal.
3. A statement of the type of the service for which the equipment is desired and the conditions under which it is to operate.
4. A tabulation of the information desired from the maker of the proposal, covering guaranteed performance of the equipment under various conditions of operation and on which operating efficiencies are based.
5. A statement of correction factors and allowable variations from guaranteed performances.
6. A statement of general and particular design features, leaving the manufacturer as free as possible, however, to utilize his standard designs in what he has to offer.
7. A list, with particulars, of any accessory equipment that is to be included in the proposal.
8. A statement of any shop and field tests that are desired, fixing responsibility for the making and costs of such tests.
9. A list of drawings and physical data pertaining to the equipment that may be required by the purchaser.
10. The date of shipment and the time required for erection.

Preparation of Proposals

Frequently, requests for proposals ask for data and drawings which, while necessary for the final working out of the engineering design and efficiencies of a project, are not required in the amount of detail requested for the determination of the successful bidder.

Modern equipment is complicated at best, a great deal of it being "tailor made." Preparation of a proposal for such equipment is a task in itself, requiring care and time, which if not taken may result in the submission of inaccurate data and erroneous prices. These may affect the proper evaluation of the proposal and result in the selection of less desirable equipment, with the probability of subsequent argument with the successful bidder. In asking for bids, therefore, a sufficient interval should be given in order to permit of the preparation of considered proposals.

The selection of the successful bidder, from among the proposals submitted, requires a careful comparison and analysis of the prices, data and information contained in the bids received. If the specification has been prepared properly, these should be in such form that they can be recorded readily and in such manner that differences are apparent. Each bidder will probably submit additional data to those requested, which pertain to the merits and characteristics of the particular type of equipment manufactured by him. Performance figures can then be studied in the light of their effects on the efficiencies, both of the equipment itself and the plant as a whole. Data as to details of construction will give an idea as to relative strength, operating reliability and probable maintenance.

Margin of Prudence Desirable

In giving consideration to these matters there should be kept in mind the possible optimism of a bidder with respect to his own equipment and the probability of the performance figures given being attained in regular and sustained operation. There are certain features in connection with each type of equipment, which if not defined in the specification, but left for the bidder to decide, may be found not to have the margin of prudence which the engineer considers desirable or necessary. This is no reflection on any manufacturer who naturally has a high regard for his own product, and must face a like opinion on the part of his competitors.

Having decided on the relative suitableness of each proposal with respect to efficiencies, reliability, dates of delivery and erection and other pertinent points, consideration can be given to the prices quoted. Again, if the specification has been sufficiently definite and its provisions have been followed, it should be possible to accept the quotations at face values. One should make sure, however, that figures and data are comparable, that nothing has been omitted or added and that the conditions set forth in the specification have been complied with.

Merits of Equipment Versus Price

Next in order comes the comparison of the merits of the quipment with the prices quoted. In some cases engineers are not given the latter, but are asked to establish price differentials between the various proposals based on their evaluation of the guarantees, data and information furnished. The author has no quarrel with this method except to state that often there are collateral considerations to which an exact money value cannot be applied, but which nevertheless may make it desirable to make an award on other than the basis indicated by the analysis, provided the margin of price is not too great. For instance, in cases where equipment is to be purchased that is similar in type and operating conditions to that installed already, there may be an advantage both from design and operating standpoints in keeping to the same manufacturer, provided experience with the previous equipment has been satisfactory.

Engineering and construction costs should ordinarily be less when similar equipment is installed, the installation details of which have been worked out previously. The opinion is expressed sometimes that it is an advantage to have only one manufacturer to deal with in matters of inspection, maintenance and amounts of repair parts carried. On the other hand, competition is an urge toward the production of more efficient and reliable equipment, and its continuation is of benefit to the purchaser and to the equipment manufacturer alike.

The author has endeavored to set down some of his ideas on an important subject. He realizes that after an engineer's analysis and recommendation have been made, other considerations may make it desirable to award an order on a reciprocity basis. No exception can be taken to this by the engineer provided the equipment selected, in his opinion, will perform efficiently and reliably.

How to Use Laboratory Tests in JUDGING COAL VALUES

By G. B. GOULD, Pres.,
Fuel Engineering Co. of N. Y.

Although individual shipments of coal from the same mine may vary widely as to certain properties, variations in quality follow a known, statistically determined pattern when applied to a sufficiently large number of carloads. Maximum variations are often more important than average quality and the correct interpretation of data is as necessary as proper sampling and testing. Information is given as to what both buyer and seller should expect with regard to variations in a series of shipments, and the relation of coal specifications to the normal pattern is discussed.

THE coal that was mined today was never mined before, and will never be mined again. This simple, but often overlooked, fact is one of the chief reasons why the appraisal of coal values is never a matter of complete certainty, but one of *calculated probabilities*.

Another reason, even less generally understood, is that every shipment of coal is a *mixture* of materials having widely different properties. For example, a shipment of coal which is said to have 8 per cent of ash, actually may contain individual pieces that contain less than 2 per cent of ash, and others that have 50 per cent or more of incombustible material. In a shipment of coal for which the softening temperature of the ash has been found to be 2600 F, the ash in many of the pieces will have a softening temperature over 2800 F, while the ash in some of the others will fuse at 2100 F or lower. So does the per cent of volatile, or sulphur, or the Btu value also vary among the individual pieces of coal which comprise any shipment.

Consequently, the quality of individual shipments from any mine would vary according to the proportions of these different materials which happen to find their way into each carload, even if the seam from which they are mined were continuously uniform.

The accurate appraisal of coal values is an important matter, one that represents real money to the industrial buyer of coal. Unless one understands that every appraisal of coal values, that every measurement of the quality of a lot of coal is a matter of calculated probabilities, there is a real risk of costly miscalculation, and of missing the most fruitful uses of the methods which have been developed for the measurement of the quality of coal. These probabilities can be calculated.

The author is not suggesting that every coal buyer take up in a serious way the mathematics of probability as it relates to variations in coal quality. But he should understand that these variations do follow known mathematical laws, that they are sure to occur, and that they are predictable. With a general understanding of these principles, the purchaser will find that his use of laboratory test data, whether tests of coal he buys, or test data supplied by salesmen, or found in books, will be much more discriminating. He will know better what to expect and what to guard against; and it may help him to understand that the accurate use of such data, whether in buying or selling coal, or in interpreting boiler performance records, is just as important in the final result, as is the accuracy of the methods employed in producing the data in the first place.

In fact, a great deal is said about the accuracy of methods of sampling and testing coal, but almost no attention is paid to the equally, and perhaps even more important matter of interpreting the results of these tests. The sampling and testing of coal can be reduced to a routine, but the use of the data thus obtained depends upon a combination of technical knowledge, experience and trained judgment.

Variations in Quality of Coal Follow a Known Pattern

If one hundred shipments of the same coal are sampled and tested in the laboratory, there will be a certain amount of variation among the results. If this be a bituminous coal, having an average of 8 per cent ash, and if all of the hundred ash determinations are arranged in order, from the lowest to the highest, it will be found that they fall into a pattern which will closely agree with the diagram shown in Fig. 1.

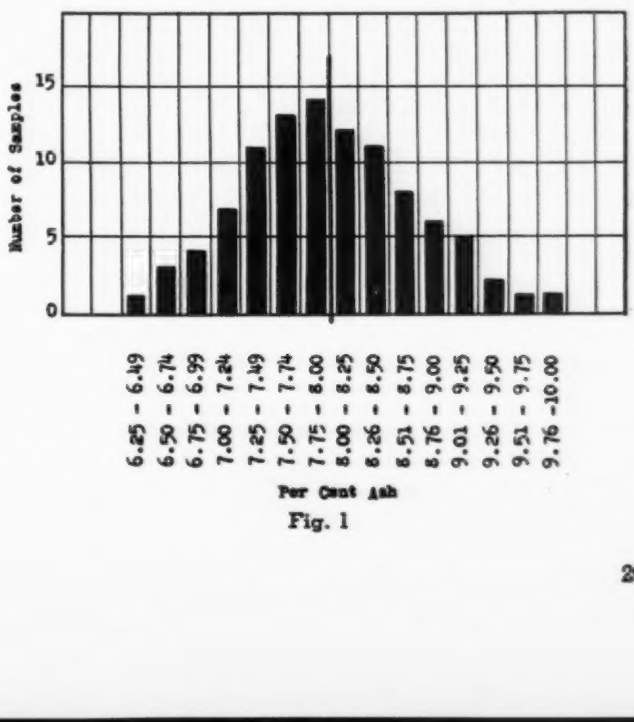


Fig. 1

The fact that laboratory tests of coal follow this pattern almost universally has been established by statistical studies of thousands of tests, which have been made independently by research investigators in this country, in England and in South Africa. And this is true not only of the percentage of ash, but also of sulphur, Btu and softening temperature of the ash. It is not true of moisture, which is an independent variable governed by the weather and by the conditions to which the particular lot of coal has been subjected in transit or storage.

If the coal has a higher average percentage of ash, or if the sampling methods are very bad, the range from high to low will be greater than in the diagram shown, but the pattern will be the same. If the coal is a mechanically cleaned, barley anthracite with an average of 11 per cent ash, both the pattern and the range will agree with this diagram.

Without going into the mathematics, the pattern of this diagram conforms very closely to what is known as the normal curve of probability, but with one important exception. To follow it exactly, the pattern would have to be symmetrical, but this one, it will be noticed, is slightly unbalanced. There are more tests near the average and slightly below it, than there are within the same range above it. To compensate for this preponderance of tests close to the average but on the low side, the high ash determinations, though small in total number, exceed those which are an equal distance on the low side.

The fact that coal test data fall into this pattern would not be so important, if this were a random arrangement. Back of it are some mathematical laws, which make it possible, once the characteristics of a coal are known, to predict with surprising accuracy the number of tests out of, say, one hundred, which will fall within any given range above and below the average, and the maximum variation that can be expected once in one hundred, or one thousand or ten thousand tests.

Typical Pattern of Variation in Sulphur and Ash-Softening Temperature

The diagram is repeated in Fig. 2 with typical scales for per cent of sulphur, and softening temperature of ash, simply to give a general idea of the approximate range of variations in these measurements that are likely to be encountered. Just as in the case of the per cent of ash, the total range of variation will differ among coals. For the sulphur, like the ash, the infrequent maximum variation is likely to occur on the high side, but for the softening temperature of the ash the greatest variation is more likely to be found on the low side.

Every one who uses laboratory coal test data should, at least, have the pattern of this diagram in his mind's eye, remembering that every test fits into a pattern like this somewhere. The pattern is practically universal in its application;[1] only the range of variation changes. As far as the percent of ash is concerned, the range will not be significantly smaller than that shown on the sample diagram, except for coals much lower in ash than 8 per cent.

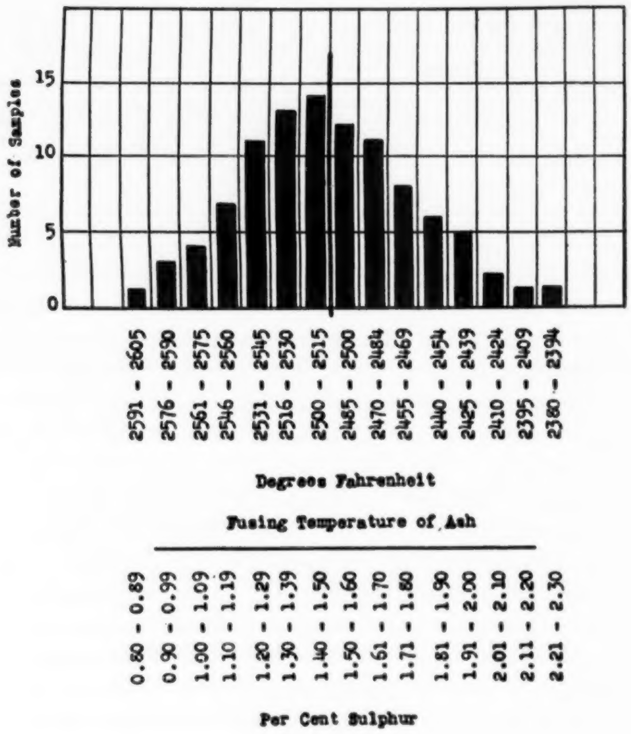


Fig. 2

In what follows, reference will be made chiefly to variations in per cent of ash, not because this determination is of paramount importance, but because the principles involved which apply equally to sulphur, softening temperature of ash and Btu can be more simply and easily illustrated without confusion, in this way.

Why Single Laboratory Tests Are Not Satisfactory in Judging Relative Coal Values

Keeping the form of the diagram in mind, any one test of a given coal may be the one in one hundred that happens to fall as indicated by the arrow in Fig. 3. Likewise,

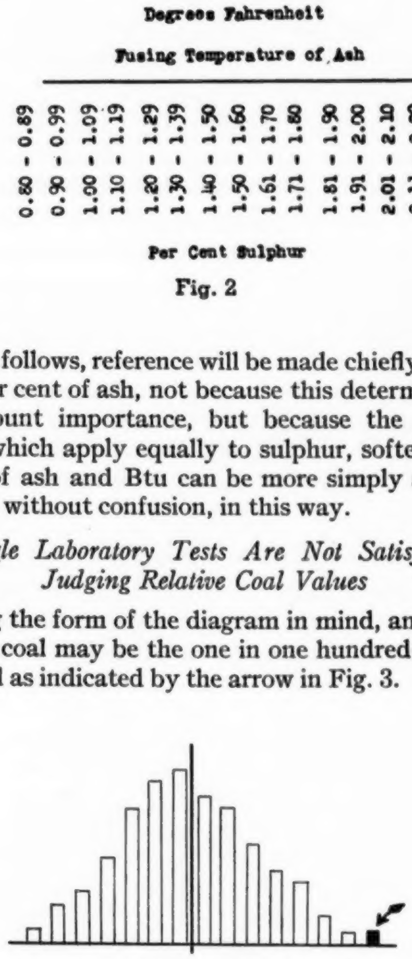


Fig. 3

any one test of another coal, with which one may want to compare the first one, may fall in the diagram at the point indicated in Fig. 4. Or two single tests of two coals

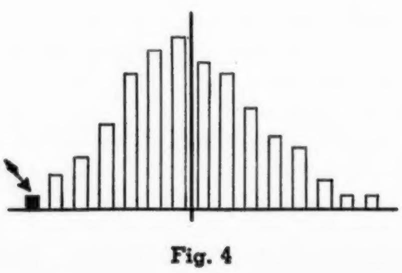


Fig. 4

[1] There is one exception to this general statement. When coal from two mines is shipped as a single product, if the average qualities from the two mines differ, the result will be a diagram which has two centers of concentration, one above and the other below the general average, instead of being grouped around it. The same thing will occur if the coal from two sections of a mine differs in quality. It is only by a diagram of this kind, that such a condition can be readily identified and distinguished from the ordinary type of variation.

may have the relation to each other, and to their respective averages as indicated in Fig. 5.

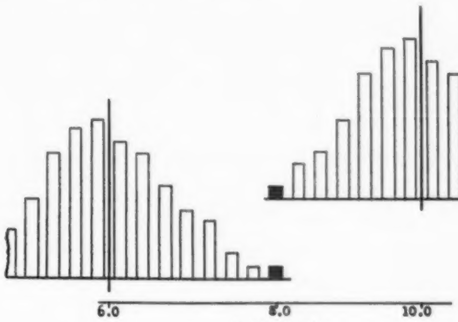


Fig. 5

Two such individual tests standing alone would indicate coals of equal value, while the truth is that over a series of shipments one coal will prove to be worth considerably more than the other. Of course, they may fall anywhere else, within the typical range for each coal. The point is that with only one or two samples and tests of each coal to judge by, there is no way of knowing, or even of guessing, where they belong in the pattern of variations.[2]

Probable Maximum Variation Sometimes More Important Than the Average Quality

There is one important difference between the variations in per cent of ash, and those which occur in the per cent of sulphur and in the ash-softening temperature, when appraising relative coal values for specific uses. In most cases, normal variations in the per cent of ash can be and are tolerated in actual plant operation, but in some industrial processes a variation in sulphur above a certain limit, even for an occasional shipment, may be costly. Similarly, in some steam plants, an occasional maximum variation in ash-softening temperature on the low side may be very troublesome. In such cases, an understanding of the normal pattern of variation is of particular importance in judging of the suitability of individual coals, because the danger of being misled by a simple statement of an average value, or by a few scattered tests of individual shipments is greatly magnified.

Consequently, in judging coals, one is primarily concerned with the absolute value of the average for the per cent of ash and the Btu, and only secondarily with the individual variations above and below the average. But when it comes to the per cent of sulphur, or ash-softening temperature, when either one is important, it is primarily a matter of judging just how much it is worth to run a risk once, or five or ten times in a hundred of having the sulphur exceed a certain limit, or the ash-softening temperature fall below a specified figure.

Averages, Though Inherently More Accurate, Have Their Limitations

Obviously, coal test data become much more intelligible, and much more useful as an implement in making coal buying decisions, if one has available a reliable average value, derived from tests of a number of shipments of each coal under consideration, and especially if one knows something about the characteristic pattern of variations, which is back of the average.

To illustrate, if 2500 laboratory tests of one coal were separated by random selection into one hundred groups of twenty-five tests each, and these one hundred averages were plotted on a diagram similar to the one shown, it would be found that they would fall into the same pattern, but the *range of variation* would be reduced to *one-fifth* of what it is there. That is, about ninety of the one hundred group averages should fall within $^1/_4$ of 1 per cent of the average per cent of ash, instead of the same proportion of the individual tests between the wider limits of 6.75 and 9.25 per cent. The chance of one of the occasional maximum variations upsetting the calculations becomes negligible. In fact, there are only about three chances in a thousand of one of these group averages being more than $^1/_2$ of 1 per cent away from the average of the entire 2500 tests.[3]

But averages, while they enjoy this mathematical basis for confidence in their accuracy, cannot be blindly accepted without knowing something about their antecedents. There are mainly three things to look for. First, one must be sure that an average is composed of all of the tests in a series. There is a natural tendency, especially when such figures are used for sales purposes, to throw out at least the three or four highest ash percentages that are sure to be found in one hundred tests, on the theory that they are exceptional and not representative of the coal. Of course, standing alone they are not, but they belong in the series, if the average value is to be a true one, and one which will be duplicated by future performance.

What few people know is that if a normal series of laboratory coal tests be altered by any major operation of selection, it can be detected by statistical analysis. Take for example an extreme case of using only the fifty-three determinations which fall below the average of 8 per cent

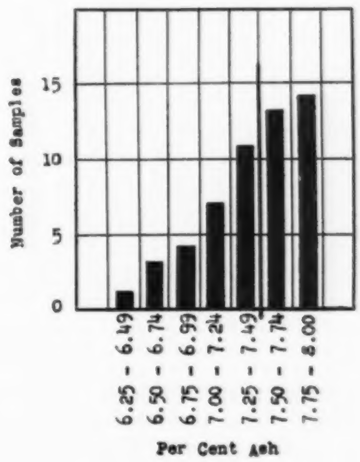


Fig. 6

in the typical diagram. The average now drops to 7.5 per cent, but these tests arranged in a diagram produce the pattern shown in Fig. 6 which, it can be seen at a

[2] It is necessary to distinguish between the use of a laboratory coal test as an indication of *the quality of one lot of coal*, and the use of one or more tests as a measure of the probable average value of a series of shipments to be received in the future. The first is primarily a matter of sampling and testing technique, which is related to and embraced in the broader use of laboratory test data in making coal buying decisions. The two divisions of the subject should be dealt with separately to avoid confusion. We are concerned here with the broader use.

[3] The accuracy of averages, when using them for coal quality data, which follow so closely the normal probability curve, has a definite mathematical relation to the variations observed among individual tests, in accordance with the mathematical principle that the magnitude of the individual variations diminishes inversely with the square root of the number of items included in the average. In practice, adherence to this rule is closer, the larger the number of items averaged.

glance, is completely abnormal, in the way that the tests are now arranged around the new average.

In the second place, a coal mine is always advancing into new territory. The consequence is that while the average quality for many mines remains surprisingly constant over a period of years, it may change at any time, and often does. Some mines, every so often, have to pass through a formation which changes the quality of the coal temporarily. Therefore, coal quality records should be constantly added to, in order to detect these changes when they occur. This is particularly important these days, when so many changes are taking place in mining methods, and in methods of preparation.

And finally, while the accuracy of averages is only slightly modified by inadequate sampling methods which merely result in chance variations that cancel each other, there are cases of both sampling methods and laboratory procedure which introduce a constant error on one side or the other. Some mechanical sampling devices, and some equipment for the crushing and dividing of coal samples, have been found to produce this kind of a constant bias. Therefore, one cannot safely take averages derived from sampling and testing of an unknown source with complete confidence. One of the best ways to detect or to protect against persistent bias in sampling is to build up a series of tests from samples taken by different consumers.

The result of a constant bias differs from artificial selection of data, in that it will probably produce a pattern of variation which conforms to the normal, but with all the values too high or too low.

Much Misunderstanding Is Due to Variations That Are Inevitable

Many unfortunate consequences in the every-day business of buying, selling and using coal, as well as a vast amount of misunderstanding between buyers and sellers, arises from ignorance of the inevitability of coal variations and of their predictability. The salesman, for example, says his coal has such-and-such a percentage of ash, volatile, sulphur and a certain Btu value and softening temperature of the ash, specifying exact figures, often to two decimal places. If these figures represent a test of one sample, they mean very little, for all they do mean is that this quality is somewhere within the normal pattern of variation for this coal. But too often, neither the salesman nor the buyer fully realizes this.

If the figures, so exactly stated by the salesman, represent an average of a series of tests, and assuming that it is a good average, the buyer is likely to expect the quality of every single lot of this coal to come much closer to the average than it will. And this brings up a point that needs to be kept clearly in mind in using averages of coal quality. An average quality derived from tests of a series of shipments of a given coal can be used with a high degree of accuracy in predicting the average quality of *another series of shipments*, but the quality of any *one* lot may fall anywhere within the pattern of normal variations. The very first shipment may be that one in a hundred at either extreme. It is possible to predict that one in a hundred shipments will be found there, but it is not possible to predict which one it will be. It may be the first or the last.

In other words, just as it is impossible to guess the average quality of a coal from a single sample, it is almost as difficult to predict the quality of any single shipment from the average. But working from the average to the single shipment, and knowing the normal pattern of variation, one has the advantage of knowing quite closely just what the odds are for or against the quality of that shipment varying from the average by any specified amount.

How Thirty Individual Shipments Varied According to the Expected Pattern

Most of these points were illustrated in an interesting way by the test results in sampling and testing thirty individual cars of one coal. The percentages of ash for these thirty samples superimposed upon the characteristic pattern of variations, which would be expected among one hundred shipments of a bituminous coal of this quality, look like that shown in Fig. 7.

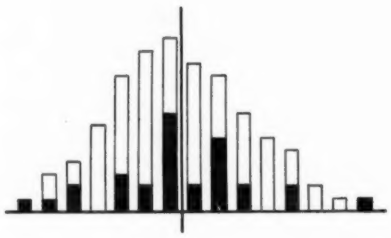


Fig. 7

Here will be seen the normal pattern of variation in the process of building. A smaller number, such as thirty, will not result in an ideal diagram, but the essential characteristics of the typical pattern are beginning to appear. The greatest concentration is just below the average, and more than half of the whole number (sixteen of the thirty) are on the low side. The maximum variation is on the high side. This maximum variation occurred in the second car of the series of shipments, and the two largest variations on the low side were the first and the sixth cars.

It so happened that the identical coal in these cars was sampled and tested a second time. The first series of samples was taken from individual cars before the coal was transferred to barges. As the coal was discharged from the barges it was sampled again. The averages of these two series of samples were as follows:

	Car Samples	Barge Samples
Ash (dry), per cent.............	7.97	7.94
Sulphur (dry), per cent.........	1.86	1.81
Btu dry........................	13850	13903

These two sets of figures, it should be noted, are not for two separate series of shipments, but of two series of samples of the same identical coal. An average of another series of shipments from this same mine could be predicted nine times out of ten to fall within $^1/_4$ of 1 per cent of this average percentage of ash, and within 0.1 per cent of the sulphur figure obtained from this series, assuming that no major change took place in the mine, or in the mining methods in the meantime.

Chances in Predicting Quality of Coal in a Single Shipment

And so it makes a good deal of difference whether one is using an average as a basis for buying a single lot of

coal, or for a series of shipments over a period of time. If a single shipment of coal is bought upon a representation of average quality for the coal, there is slightly more than an even chance that it will be better than the average, but there is also the practical certainty that every so often one of those extreme variations on the low-quality side will turn up.

If there is no explicit understanding between the buyer and the seller as to just what these chances are, presumably the seller runs the risk, and he should not complain if the buyer claims an adjustment when he gets one of the less frequent lots that are on the low-quality side. The buyer can hardly be expected to take the chance, unless he is told in advance just what the risk is, and that risk can be mathematically expressed by a frequency diagram. Of course, the salesman, who is probably having a hard enough time to get the order, is unlikely to make his job harder by explaining this risk, even if he understood it, which he seldom does.

To the coal salesman, any one of these predictable major variations on the low-quality side is merely the result of poor sampling or improper testing, or almost anything except one of the infrequent but inevitable variations in the quality of the coal. Occasionally, he is right, but very much less often than is popularly supposed. We know that this is so, from the thousands of series of tests and group averages, which we have built up and maintain, from samples of coal taken by industrial consumers and by our own samplers, now embracing some 130,000 tests.

Both Buyer and Seller Ought to Know What Variations to Expect in a Series of Shipments

It is a different situation, when an average quality is used in making a sale of a series of shipments. In that case also, the buyer should be informed as to the probabilities of variation in quality. Within this range, the buyer has no good basis for complaint, provided the average quality for the whole series of shipments is reasonably close to the sales claim. Some individual lots will be worse than the average, but the way coal is commonly sold, the buyer is left with the impression that no individual delivery will be below the represented quality. The result is, quite naturally, that the buyer takes for granted the shipments which are better than the average, and complains about those that are of lower quality.

The fact that variations in coal quality are inevitable, and that they will take place according to a predictable pattern, even when there is no substantial change in the average coal quality, does not relieve the producer of responsibility for maintaining quality, or of keeping the range of variation at a minimum. Nor does it relieve him of the responsibility of delivering coal that equals in quality the claims his salesmen make for it. If he is willing to have his customers think that his coal will vary less from its average than it will, as shown by commercially accepted methods of measuring quality, or that no shipment will ever fall below the average quality (an obvious mathematical impossibility), the dissatisfaction, the complaints and disputes that arise from that procedure are largely of his own making.

These situations are not due to any lack of good-will or fairness on the part of buyers, nor, in many cases, to any deliberate intention on the part of the coal producer to mislead, but to an almost complete lack of knowledge among individuals, on both sides, of the statistical characteristics of the variations in coal quality, as measured by the best methods that have been found for its measurement. And it is through no fault of their own that this is so. No one who has but a small number of coal tests to deal with could be expected to discover for himself the mathematical significance of these variations. In fact, it is impossible, except through intensive study of thousands of tests; and this requires a vast amount of detailed calculation, as well as some knowledge of statistical principles. Only within the past few years has the subject attracted the attention of fuel engineers, and only a handful of them at that, scattered over the whole world. This article, so far as the author knows, is the first attempt at what might be called a "popular" explanation of the subject, and its practical every-day significance.

Coal Specifications and Their Relation to the Normal Pattern of Variation

These statistical characteristics of coal quality have a special bearing upon the matter of specifications for coal, and upon "penalty-and-premium" contracts. When the quality of coal is definitely specified, there is a tendency to specify what is really an average of quality, but to use it as a *limit* of quality below which no single shipment is expected to fall.

With the typical pattern of normal quality variations in mind, it is obvious that if the quality which is stated is the average quality expected, nearly half of the shipments will surely fall below the quality specified. And it is also obvious that if the normal pattern of variation for a given coal is known, there is a calculable relation between the average and the low limits of quality which are likely to be exceeded once in every so many shipments.

When no premiums are allowed, but penalties are assessed, the practical effect is to make the average quality a *limit* of quality. This means that a coal, to escape all penalties, must have an average quality much better than that specified. Such coal is likely to be much better than the buyer intended to specify, and may easily be better than any coal which can be offered.

Under such circumstances, any bidder must expect to suffer some penalties. Just how many penalties and how severe they will be depends upon the quality of the coal and upon the terms of the contract. The fact is that it is possible, if one knows the normal pattern of variation for a coal, to forecast, quite accurately, just what these penalties will be, if a substantial number of shipments is going to be made, and separately sampled and tested.

Of course, it is a very different matter if that kind of a contract is used to purchase a single shipment. Then the shipper runs the risk that the particular shipment may be one of the three or four out of one hundred, which will incur the most severe penalty. For such purchases, the terms of the contract should provide more latitude than when a series of deliveries is called for.

But in any event, when what should properly be the average quality of the coal to be bought, is in effect made a limit of quality, the bidder is quite likely to over-estimate the risk of penalty and include a larger safety factor in his price than he needs to.

Of all its practical applications, it is in the preparation of such specifications, and in bidding on them, that a

knowledge of the statistical characteristics of coal is most essential. The buyer can easily and quite unconsciously defeat his own purpose by eliminating offers which would be desirable, or by causing bidders to allow too much to properly cover the risk of penalty, or by forcing the quality of coal that can be safely offered much above the level really wanted. Every coal specification, and every contract involving price adjustment for variations in quality should be designed individually for the type of coal to be bought, the location in which it is to be used, and the number of shipments to be made.

Difficulty in Using Published Fragments of Coal Quality Data

Lack of understanding of the statistical characteristics of coal tests often leads to the mistake of placing too much reliance on fragments of data, collected from a variety of sources. More and more of such fragmentary coal quality data are finding their way into publications of one kind or another. In the hands of those with a broad and detailed background of knowledge concerning coal, such data have some value because they know what weight to give to them, but to broadcast such collections is like distributing firecrackers to the kindergarten. A lot of burnt fingers are sure to result.

It would be easy to cite dozens of cases of fragmentary coal quality data, which standing alone and interpreted without a proper understanding of the particular pattern of normal variations to which they belonged, would be either valueless, or misleading for purposes of appraising the relative values of competing coals. Such data are made a public record by Government departments, not necessarily as conclusive evidence of the quality of a given coal, but for what they are worth, on the presumption that the user will have a sufficient knowledge of the subject and experience to know what weight to give to this information. The important point is, that from what is known about the normal variations in quality among different lots of the same coal, no one should expect to form, from a few fragments of data, no matter how authentic the source, as accurate conclusions of the relative values among competing coals as are necessary in buying ten, twenty or fifty thousand dollars worth of coal.

Individual Tests Have Their Own Distinctive Value, If Properly Interpreted

On the other hand, the inevitable variations among tests, unless their real nature is understood, lead some people to think that they are simply random deviations and that the data are of little value. They thus deny themselves the benefit of an extremely valuable instrument in the conduct of coal buying, because they do not understand that tests of a variable material like coal have to be used in an entirely different way from tests of homogeneous and uniform materials like metals.

Laboratory tests of single samples are important in themselves, as well as being the necessary material out of which series of tests (and their averages) are constructed. These single tests of individual lots of coal have their own uses, but their interpretation also requires an understanding of what kind of measurements they are. When the nature of these measurements is examined, it has been found that they too follow the same mathematical principles. This subject will be discussed by the author in a second article to appear in the November issue.

High Pressures and Temperatures in Marine Power Plants

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This paper, of which the following is an abstract, was presented before The Society of Naval Architects and Marine Engineers.† While intended as an analysis of problems to be solved in the application of high steam pressures and temperatures to marine installations, much of the text is equally applicable to land practice and, in fact, is based on studies and experience with the latter. The characteristics of suitable materials are discussed at some length.

POWER plants for ship propulsion operate under very different circumstances from those on land, and it is only natural that here the advance toward high steam conditions should be more cautious. A large percentage of our ships use power plants which are small compared with land installations, and which for that reason alone would not ordinarily be built for the highest steam conditions. On the other hand, the economical incentive for reduced fuel consumption is probably greater than on land, while the question of reliability is bound to have greater weight. It is a perfectly safe prediction, however, that once the new basic conditions have proved their worth on land, they will be applied in a guise suited to the conditions of ship operation.

The main aspects of the actual thermal cycles in use are determined principally by the characteristics of water vapor. These cycles are such that an increase in temperature alone does not bring about much improvement of efficiency; it is only when both pressure and temperature are increased that an appreciable gain in efficiency is realized. Moreover, because of the presence of moisture in the exhaust blading of turbines, there is a restriction of the choice of pressure which can be used in combination with a certain temperature.

When a certain limit in maximum steam temperature has been established, it is possible to construct a thermal cycle of optimum efficiency. This cycle represents a compromise of technical and economical considerations. The means available to us for enhancing this optimum efficiency in steam cycles are *reheating* and *regenerative feed heating*. Assuming a present practical limit in maximum temperature of 900 or 950 F, it is questionable whether reheating will prove an economical possibility. This leaves us with the regenerative feed-heating cycle as the most promising approach to higher operating economy. The number of extraction points becomes an economic problem, the solution of which will depend on the conditions of each individual application.

† At the Massachusetts Institute of Technology, Cambridge, Mass., May 23, 1939.

Choice of inlet pressure depends upon the permissible exhaust moisture, the steam flow through its influence upon the efficiency of the first stages, and a variety of economical considerations. Under present premises, the very high pressures can probably be justified only for the largest capacities.

Table 1 gives a comparison of ideal efficiencies of a series of plant conditions. These efficiencies are based on zero losses throughout the cycle. The extraction points for feed heating have been placed so as to divide the enthalpy drop in equal parts. On this basis there is a possible fuel saving of about 25 per cent between 400 lb per sq in., gage, 700 F, and 2400 lb per sq in., 950 F. The actual saving will probably be somewhat less.

TABLE 1—IDEAL EFFICIENCIES; $28^1/_2$ IN. VACUUM

Plant	*A*	*B*	*C*	*D*	*E*	*F*
Pressure, lb per sq in., gage	400	600	800	1200	1800	2400
Temperature, deg F	700	750	850	900	950	950
Carnot efficiency, $1 - T_2/T_1$	0.525	0.544	0.579	0.594	0.609	0.609
Ideal efficiency, straight condensing	0.355	0.375	0.394	0.412	0.430	0.438
Feed heating						
In stages	2	2	3	3	4	5
To temperature, deg F	320	349	406	441	507	570
Ideal efficiency	0.383	0.409	0.428	0.461	0.500	0.510
Saving, per cent	0	6.4	10.5	17.0	23.3	25.0
Exhaust moisture, per cent						
Turbine efficiency, 70 per cent	6.0	6.6	4.9	5.6	6.6	8.9
Turbine efficiency, 75 per cent	8.2	9.0	7.4	8.3	9.5	11.8
Turbine efficiency, 80 per cent	10.4	11.3	10.1	11.1	12.4	14.6

The applicability of any one of these plants to a given case depends principally upon the moisture content in the exhaust. With present means of erosion protection and moisture removal of the last row blades, this moisture content probably can be raised beyond the limit of 12 per cent, which has become conventional on land installations.

Probable Direction of Developments

The water-tube marine boiler has reached a high degree of development and there is every reason to believe that existing types will satisfactorily take care of the advance toward the limit in temperature, which is permitted by present materials. This limit is probably about 950 F. However, if the steam pressures are to advance materially

beyond 1200 lb per sq in., and the gains in efficiency and weight make such an advance likely, the forced-circulation type of boiler becomes an almost inevitable part of the development.

The next question of vital importance concerns the choice of thermal cycle. If re-heating is regarded as an economical possibility, the choice of operating pressures is considerably widened, and valuable improvements in efficiency may be made without going to the extremes of steam temperatures. This question has been given careful study over many years on land stations, and the verdict here appears to be in favor of the non-reheating type of plant. Where reheat is considered at all, it is almost without exception a question of boiler reheat. The pressure losses and operating difficulties which have characterized steam reheaters appear to make them much less desirable. It is possible to conclude from this that the decisions on marine power plants will be preponderantly in favor of the non-reheat type of plant.

Introduction of the forced-circulation boiler might possibly bring about a fundamentally different solution of the question of feed heating as well as reheating. The rigid separation between boiler plant and turbine plant, which is characteristic of existing designs for both land and marine installations, is undoubtedly a relic from the steam plants of the last century. To combine them both into one assembly appears visionary at present, but some day this solution is bound to appear. Land developments already show tendencies in this direction.

Mechanical Properties of Metals at High Temperatures

Up to a few years ago the problem of mechanical strength of engineering structures was viewed entirely from the point of view of strength in the elastic sense. The most important advances on the subject of mechanical strength relate to the growing conviction that the non-elastic properties of our materials are more important than the elastic properties, and much more significant in relation to failure. This is particularly true at elevated temperatures. The problem of *creep* has been singled out as the most important of these non-elastic properties.

Our principal source of information on this property

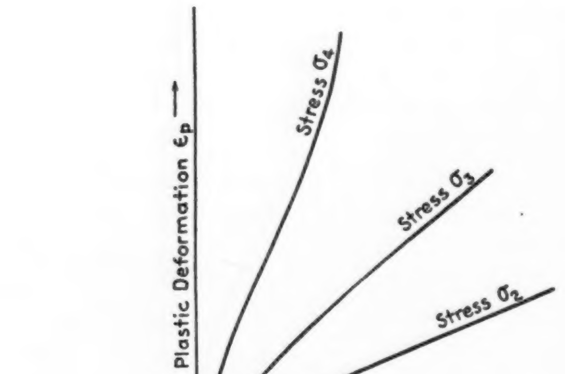


Fig. 1—Typical creep curves

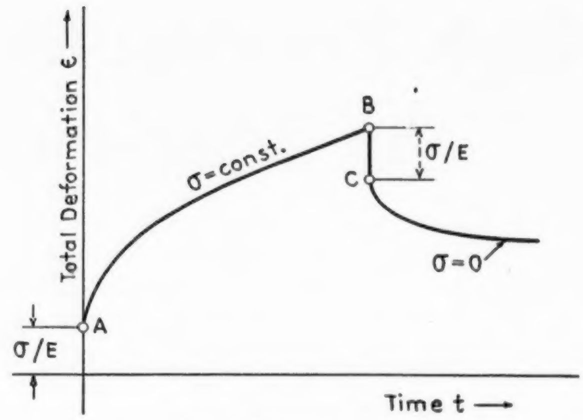


Fig. 2—Creep recovery

is the tensile creep test, in which a tensile test specimen is kept at constant stress and constant temperature, the elongation being recorded as a function of time. Fig. 1 shows qualitatively the information which is obtained from such a test. This shows the plastic deformation plotted as a function of time. Each curve represents a certain stress, the higher curves corresponding to the greater stresses. At the beginning of the test the deformation increases very rapidly; the rate of deformation then falls until, after a few months, it reaches a steady value. This steady state appears to be possible, however, only for moderate stress. For very high stresses the conditions pictured by the top curve will prevail. Here the rate of deformation reaches a minimum value, but this condition cannot be sustained; the rate keeps on increasing until fracture occurs.

The plastic deformation is usually regarded as synonymous with the permanent deformation, which remains after the load has been taken off. This is true the instant the load is removed, but if the specimen is left at temperature without load, it will contract gradually with time so that a part of the plastic deformation is recovered. This phenomenon is called *elastic after-effect* or *creep-recovery* and is illustrated in Fig. 2. The elastic after-effect is usually not large and may often be ignored for practical purposes.

For a limited range in stress and temperature, therefore, each material will exhibit the type of creep properties illustrated by the curves marked σ_1, σ_2 and σ_3 in Fig. 1. The plastic deformation ϵ_p (see Fig. 1) may be regarded as the sum of an initial value ϵ_p plus the quantity $\epsilon_\infty \times t$ which increases at the rate $\epsilon\dot{\epsilon}_\infty$. For long periods the former is unimportant, so that the possible deformations depend essentially on the *creep rate* $\dot{\epsilon}_\infty$. The enormous amount of creep testing which has been done during the last decade has had for its principal object the determination of this creep rate for various operating conditions of different materials.

For most of the steels of interest in the present connection this creep rate depends approximately upon stress and temperature in such a manner that *an arithmetical increment in stress or temperature brings about a geometrical increment in creep rate.* This law makes it possible to determine the increments in stress and temperature which are required to double the creep rate.

Table 2 shows a set of values of the creep rate at a certain stress and temperature, as well as the values of these increments, for three steels. These figures are approxi-

mate and may not always be duplicated. This applies particularly to the creep rate, but also to a lesser extent, to the increments. To take a specific example, assume that cast carbon steel has given satisfactory performance at a stress of 7500 lb per sq in. and a temperature of 850 F. The creep rate of Table 2 corresponding to these conditions is 0.1×10^{-6} $(1/h)$ or 1 per cent in 100,000 hr.

TABLE 2—INFORMATION ON CREEP

Material	Minimum Creep Rate: At Stress, Lb/In.²	At Temp., °F	$\dot{\epsilon}_\infty$ 1/h. 10^6	Increments Required to Double Creep Rate: In Stress, Lb/In.²	In Temp., °F
Forged 0.35C steel	7500	850	0.7	1200	25 to 18
Cast 0.35C steel	7500	850	0.1	1700	25 to 20
Cast 0.35C–0.4Mo steel	7500	950	0.3	2400	30 to 25

If the temperature were advanced to 950 F, the creep rate would double approximately five times; that is, it would be $2^5 = 32$ times as large, or 32 per cent in 100,000 hr. This might well be disastrous. To compensate for this by a decrease in stress would require enormous increases of wall thicknesses.

One of the most important aspects of the problem, therefore, is the extremely rapid increase of creep rates with increases of temperature and stress which characterize all of our materials. Successful operation at a certain temperature does not ordinarily give assurance that an increase of 50 F in the operating temperature is permissible without a major rearrangement of the design. The premises of design of most of the essential elements of power plant equipment are such, on the other hand, that a fundamental departure from certain proportions may bring in new, equally serious problems.

This makes it imperative that advances in inlet steam conditions be based upon the development of new materials. Important progress in this direction has been made in recent years, and the problem is being studied in many institutions. The addition of molybdenum is probably the most important single item in this development, so that 0.35C–0.5Mo steels have already become common in such structures as turbine cylinders, valve bodies, piping, etc. As indicated by Table 2, the cast C–Mo steel at 950 F may be expected to compare favorably with cast C steel at 850 F. This is, of course, a rough rule which may not hold for all types of steels, but in general it can be said that the introduction of molybdenum permitted an advance in operating temperature of 50 to 100 F.

For more highly stressed applications more complicated steels have been introduced which have much smaller creep rates; 0.4C–2.5Ni–0.7Cr–0.3Mo is widely used for turbine rotors, while the 0.1C–12Cr–0.5Mo steel has come to be almost universally used for turbine blading up to 925 F. These steels, however, are selected more for their strength characteristics than for their creep properties. Steel containing 0.35C, 1.0W, 0.6Cr and 0.5Mo is finding a wide use for important bolting applications.

The introduction of complicated alloys is accompanied with certain risks, however. There is a growing suspicion, however, that high creep strength may be attainable only at the risk of intercrystalline fractures for large deformations. With this in mind, one must concur with the view that the carbon steels should be used wherever possible in preference to alloy steels even at the expense of theoretically higher creep rates.

Up to this point the creep problem has been discussed from the point of view of structures under simple tension, such as an ordinary tensile test piece. Very few of our engineering structures have this simple configuration, so that the test information is of little use unless it can be extrapolated to more complicated types of applications. Much progress has been made in this respect in recent years and it is safe to state that the extension to combined stresses can now be made with sufficient accuracy for practical purposes so long as the stresses remain constant in time.

The case of thin tubes under internal pressure is important in power plant design because of its application to piping and boiler tubes. The data for this case are given in Fig. 3. The stress $\sigma^* = pd/2\delta$ (when p is the

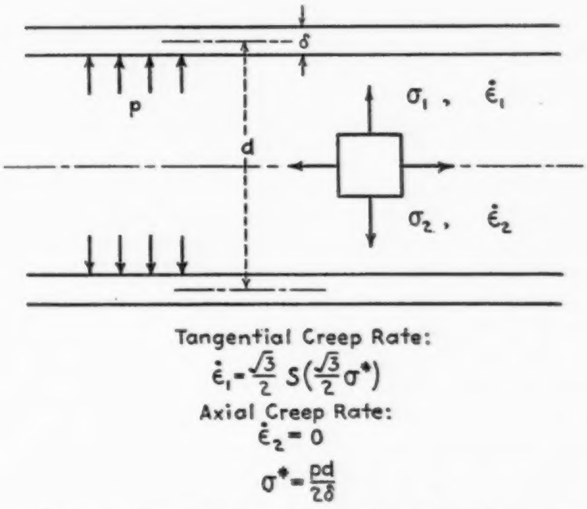


Fig. 3—Creep of thin tube under internal pressure

internal pressure, d the mean diameter and δ the thickness of the tube) is close to the usual working stress for the tube. This stress is multiplied by $\sqrt{3}/2$; that is, the creep rate corresponding to this stress, obtained from the experimental curve, is multiplied by $\sqrt{3}/2$; and the result is the tangential creep rate of the tube. Multiplying this creep rate by the diameter gives the rate of enlargement of the tube diameter. The axial creep rate is zero, a fact which has been checked experimentally. A steam pipe of forged 0.35C steel, subjected to 7500 lb per sq in. will thus have a tangential creep rate of 0.3×10^{-6} $(1/h)$, while the creep rate for a tensile test piece at 7500 lb per sq in. is 0.7×10^{-6} $(1/h)$.

When the stresses do not remain constant in time, the premises for the calculation are not so clear. The most important example in this class of problems is the bolted joint. The bolts may be assembled at an initial stress of 50,000 lb per sq in.; but after a year this stress may fall to 15,000 lb. Unless the bolts are re-tightened periodically, the joints must be designed to remain tight for the lower stress. It is a matter of importance, therefore, to be able to predict the reduction of stress with time. The ordinary tensile creep tests do not give sufficient information for an exact solution of this problem, but the following method gives at least a qualitative picture of the process.

For this purpose the creep results are plotted to give the inverse of the creep rate as a function of the stress. Fig. 4 gives such a result for a hypothetical bolt steel at 850 F. The area under this curve between two limits of

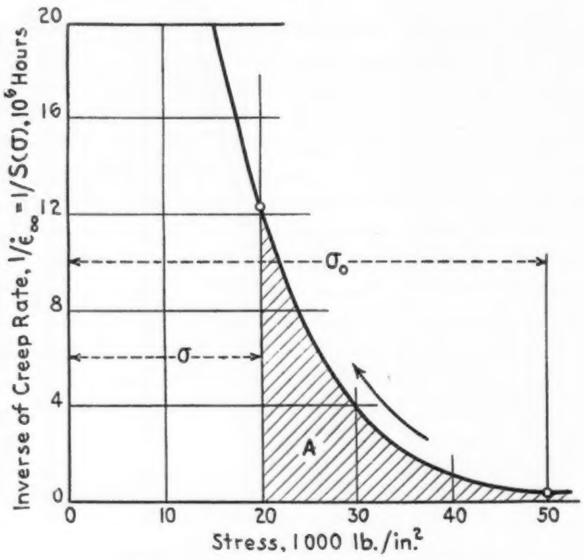


Fig. 4—Construction for time of relaxation

stress, divided by the modulus of elasticity, gives the elapsed time. Fig. 5 shows the result of such a calculation for the basic information given by Fig. 4. It shows that for this case the stress will fall from 50,000 to 20,000 lb per sq in. in 5000 hr.

The method shows clearly that an increase of the initial stress contributes little to the elapsed time, while a slight lowering of the final stress causes an appreciable lengthening of the time. It also shows that greater elasticity of the bolt structure will increase the relaxation time.

There is still another class of creep problems which have practical importance. In very thick cylinders, for example, the stress will vary considerably between the inside and the outside. Temperature gradients may accentuate the differences still further. Creep will generally tend to reduce these differences, so that in the initial stages of the process there is a readjustment of the space distribution of the stress. Such cases require a more complicated treatment. In general, it is possible to prove that the readjustment of stress will proceed until a steady state has been reached, after which the stress will remain constant in time. These stresses naturally are much more important, from the point of view of possible failure, than the elastic stress distribution usually considered.

Fatigue

The creep problem represents only one part of the entire subject of the influence of temperature upon the strength of metals. Judged by the experience gained so far on high-temperature installations, it may not even be the most important one, although it cannot be ignored.

The phenomenon of fatigue under alternating and pulsating stress is known to become vastly more complicated with increases in the temperatures. In general, the fatigue strength drops rapidly with increases in temperature above the region of 700 F, but little is known about the laws which govern this decrease. Of even greater significance is the fact that at high temperatures the fatigue phenomenon alters its essential characteristics and complications similar to the phenomenon of *corrosion fatigue* appear.

The term, in its more generalized implication, might be used to describe fatigue characteristics in which failure will occur at any stress, or at very low stress, after a sufficiently large number of reversals. This phenomenon is almost certain to be present in steam at temperatures in excess of 850 F, and an intensive research program would be in order. This note of caution applies particularly to such details as turbine buckets, subjected to fluctuating stress where significant failures have already been encountered in high-temperature land installations.

Another phenomenon of similar character is the form of embrittlement which has been observed in bolts. Even though subjected to no rapid fluctuations of stress, there are many instances where flange bolts, exposed to high temperatures for long periods, have fractured. This has been particularly pronounced in alloys containing nickel and represents one of the reasons why Cr-Ni steels have largely been superseded by Cr-Mo or Cr-W-Mo steels. Similar phenomena have been observed in boiler drums, turbine rotors and other details. These also belong to the class of intercrystalline fractures. The progress of the deterioration is most readily detected by impact tests. It may sometimes be removed by suitable heat treatment. The elimination of nickel as a major alloying element is generally regarded as the solution of this problem, but it is not unlikely that it may again become important at temperatures above 900 F.

Wear and Seizure

There is another class of material phenomena, accentuated by temperature, which does not relate to strength, but which is certain to play an important rôle in the development of high-temperature power plants. These are defined by the terms "wear," "galling" and "seizure." Wear denotes an orderly, although usually objectionable, phenomenon; galling is the usual preliminary to seizure, which is the ultimate disaster for the detail in question.

These phenomena occur with varying intensity in many of the important details of high-temperature turbines. The most important are bolts and nuts, valve-stem packings, valve seats, supporting lugs and keys, and labyrinth strips. They become increasingly difficult with each advance in temperature.

In many cases constructional modifications may be used to avoid difficulties of this nature. The most im-

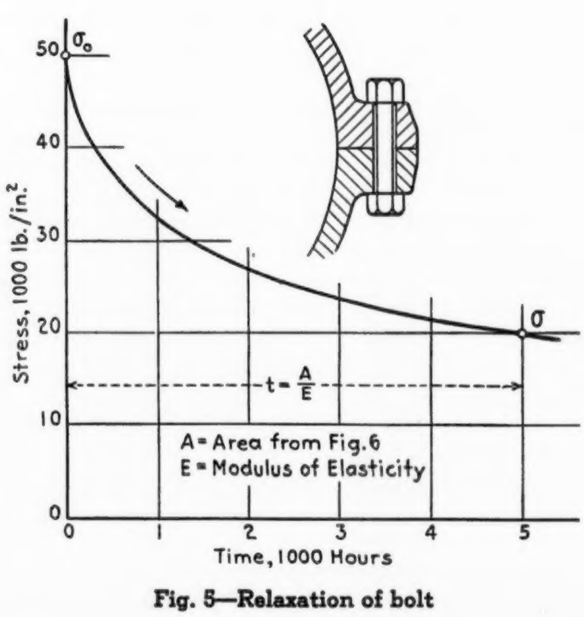


Fig. 5—Relaxation of bolt

portant example is the case of large bolts, where the present standards of thread fits cause severe concentrations of load on the first threads. High-temperature work calls for much looser thread fits. There are instances where a change of this kind alone has avoided expensive troubles.

Corrosion

There are no definite indications so far that the advance in steam temperature contemplated at present will materially alter the situation with regard to the general problem of corrosion in the path of the steam flow. Increases of operating pressure generally demand improvements in the purity of the feedwater in order to avoid fouling of the turbine blading. The changes of material of boiler tubes, turbine blades and other details, which are dictated by creep and strength, have usually contributed to reduce corrosion as well.

The land experience so far with high steam temperatures has demonstrated the need for attention to the risk of water in the oiling system, and corrosion from this cause in parts in contact with the oil. Higher steam temperatures make the problem of sealing at the ends of the turbines more difficult and increase the chance of drawing water into the oil. The presence of water in modern solvent-refined oils appears to cause more serious corrosion difficulties than in older, and for other reasons, inferior oils.

Astern Operation and Maneuvering

The design of geared turbines has always been made more difficult by the necessity for astern operation and maneuvering. The advance of the steam temperature may be expected to accentuate this situation still further.

The practice of placing the astern wheel in the exhaust cylinder rests on rational premises and may become essential in high-speed and high-temperature drives. It simplifies the problem of getting the exhaust steam to the condenser, and also reduces the idling losses. Most high-temperature projects have been based on the assumption that astern operation would be made with saturated, or at least de-superheated, steam. This may be a practical necessity for some time to come, but it would be desirable to remove this complication.

There are principally three regions in which astern operation creates serious design problems; namely, in the condenser, in the supporting structure and in the turbine blading. The astern wheel is usually a two-row Curtis wheel, with comparatively poor efficiency. Moreover, the steam distribution to the cooling surfaces of the condenser is necessarily poor, and the amount of circulating water is often decreased during astern operation. High exhaust temperatures are inevitable, from this point of view alone, leading to severe temperature problems in the condenser tubes and the condenser shell. If the latter forms a part of the supporting structure of the turbine, serious misalignments may be caused unless adequate provisions are made for the thermal expansions.

The most serious aspect of prolonged astern operation, however, is the danger of overheating the portion of the turbine which carries the ahead blading. The windage loss for an individual blade row depends upon the following variables:

(*a*) It varies directly with the density (absolute pressure) of the steam.

(*b*) It varies directly with the third power of the peripheral speed of the blading.

(*c*) It varies directly with the annulus of the blading.

(*d*) Idling in the astern direction produces windage losses which are about 10 times those for idling in the ahead direction.

The advance toward higher operating conditions serves indirectly to increase these losses through the greater possibilities for poorer vacuum during astern operation, and through likelihood of higher operating speeds.

Fire Hazard

The fire hazard incidental to failure of lubricating-oil pipes is very real at all operating temperatures above about 700 F., and there is no fundamental difference created in this respect by further advances of steam temperatures.

All steam turbines operate under severe temperature gradients at the shaft seals to the atmosphere. In a 950-F turbine the escaping steam through the glands may well be at a temperature above 850 F, and the front end of the turbine cylinder may have temperatures of the same order of magnitude. A foot or so away is a bearing pedestal, babbited bearings and lubricating oil. The success of the arrangement is associated with intensive cooling of the rotor end. In land turbines, which usually are equipped with water glands, the latter play an important rôle in this connection. Marine turbines must be equipped with glands that will seal over a wide range of speed, which rules out the water glands and their incidental advantages. No specific solution for this problem has so far been advanced except increased shaft lengths and elaboration of the labyrinth seals in the steam space and in the oil.

In large installations it is a practical necessity to actuate the control valves for the turbines with pressure oil. This carries with it a degree of fire hazard which cannot be ignored. If the failure of a pipe carrying lubricating oil should cause the oil to pour over hot steam parts, the result is almost inevitably a more or less serious oil fire. Such a fire actually occurred on the German liner S.S. *Potsdam* and caused considerable damage.

A series of rather destructive oil fires occured a few years ago in central-station turbines in the United States. These fires did not occur on units with exceptionally high steam temperatures. They led to a re-examination of central station designs which has materially influenced subsequent constructions. In a number of units the valves were actuated by a non-inflammable fluid (Aroclor). Subsequently, the valve arrangements of turbines were altered to render this complication unnecessary. The more permanent influences of these fires have been a general improvement in the quality of the details of the oiling system. Last, but not least, the fires caused increased attention to general housekeeping in the way of attention to the oiling system.

It is not implied that this land experience is generally applicable to marine practice. The use of a non-inflammable fluid for valve operation can be justified only under very exceptional circumstances. Such measures, however, as the elimination of oil piping to the very minimum, the replacement of flanged joints by welding wherever possible, the elimination of screwed fittings where possible, and the general use of seamless tubing, are certainly worth while.

Fabrication of Boiler Drums*

By A. C. WEIGEL
Combustion Engineering Company, Inc.

ONLY a few years ago, with the most modern equipment at that time, the thickest boiler drum that could be riveted was about $2^1/_2$ in., which set a top pressure limit of between 550 and 600 lb per sq in. working pressure. For higher pressures it was necessary for the boiler manufacturer to purchase high-cost forged drums from the steel manufacturers.

Development of reliable welding and the advent of the metallurgist into the boiler shop, with laboratories, microphotographic equipment, X-ray equipment, testing, impact and other highly specialized facilities, have made it possible to build reliable welded drums for higher pressure boilers at reasonable cost, and to make deliveries in much shorter time than would be possible with forged drums. Today, the only restricting factor in the size and thickness of welded drums is the size of plates obtainable. In the case of the manufacturing firm with which the writer is associated, anything other than welded boiler drums is now a rarity.

This change-over and the equipment required for constructing high-pressure thick drums, has made necessary many major and radical changes in plant equipment and procedure. Most of our drums are made of the higher tensile strength materials, generally steels having a minimum tensile strength of 70,000 lb per sq in.

Steps in the Procedure

To follow the procedure through, on drums with plates 2 in. and over in thickness, when the shells and head plates are first received in the plant they are carefully examined for surface flaws and gaged for thickness; laboratory tests are made when required or when they are necessary.

Next, the plates are normalized at the proper temperature, which varies with the steel specifications, but is usually about 1625 F. Fig. 1 shows a large plate, about $4^1/_2$ in. thick and weighing approximately 55,000 lb, being removed from the furnace car at the normalizing temperature. It will be noticed that the small sample pieces of plate are placed directly on top of the large plate so as to receive exactly the same heat-treatment.

At this point it is decided whether the plates are to be pressed hot or cold, this being determined by the outside fiber stresses and the cost of bending. If they are to be bent hot, they move directly from the plate furnace to the press, and are pressed to within approximately 90 per cent of the finished radii. The partially bent plates are then stress-relieved and finished cold so as to eliminate warping, and to permit them to be finished with very close tolerances, both in straightness and diameter. Fig. 2 shows the start of the pressing operation, Fig. 3 a subsequent step, and Fig. 4 the completed plate before being removed from the 6000-ton bending press. This press has a capacity for handling plates 40 ft long, up to approximately 7 in. thick for cold bending and is the largest press of this type in operation.

If bent cold, they are stress-relieved after normalizing, and then possibly stress-relieved one or more times during the cold-pressing operation. We feel that it is not only advantageous to finish all bending operations cold, so as to get the finished drum sheets with a minimum tolerance, but also that a certain amount of cold bending is desirable as it shows up any flaws which might exist. It is better to find such flaws in the early stage of the drum fabrication, rather than possibly at the time of drilling the holes or performing other operations which may, or may not, show up these flaws.

On completion of the bending operation, the plates are placed on a heavy machine planer (see Fig. 5) where excess metal is removed, and where the tapered sections and longitudinal grooves are prepared. After this, the shell plates are fitted together, checked and the longitudinal welds made. Fig. 6 shows the welding operation. At the time the longitudinal welds are made, the test plates are welded and attached to the drum. On the completion of these welds, the test pieces are removed, X-rayed and subjected to physical tests.

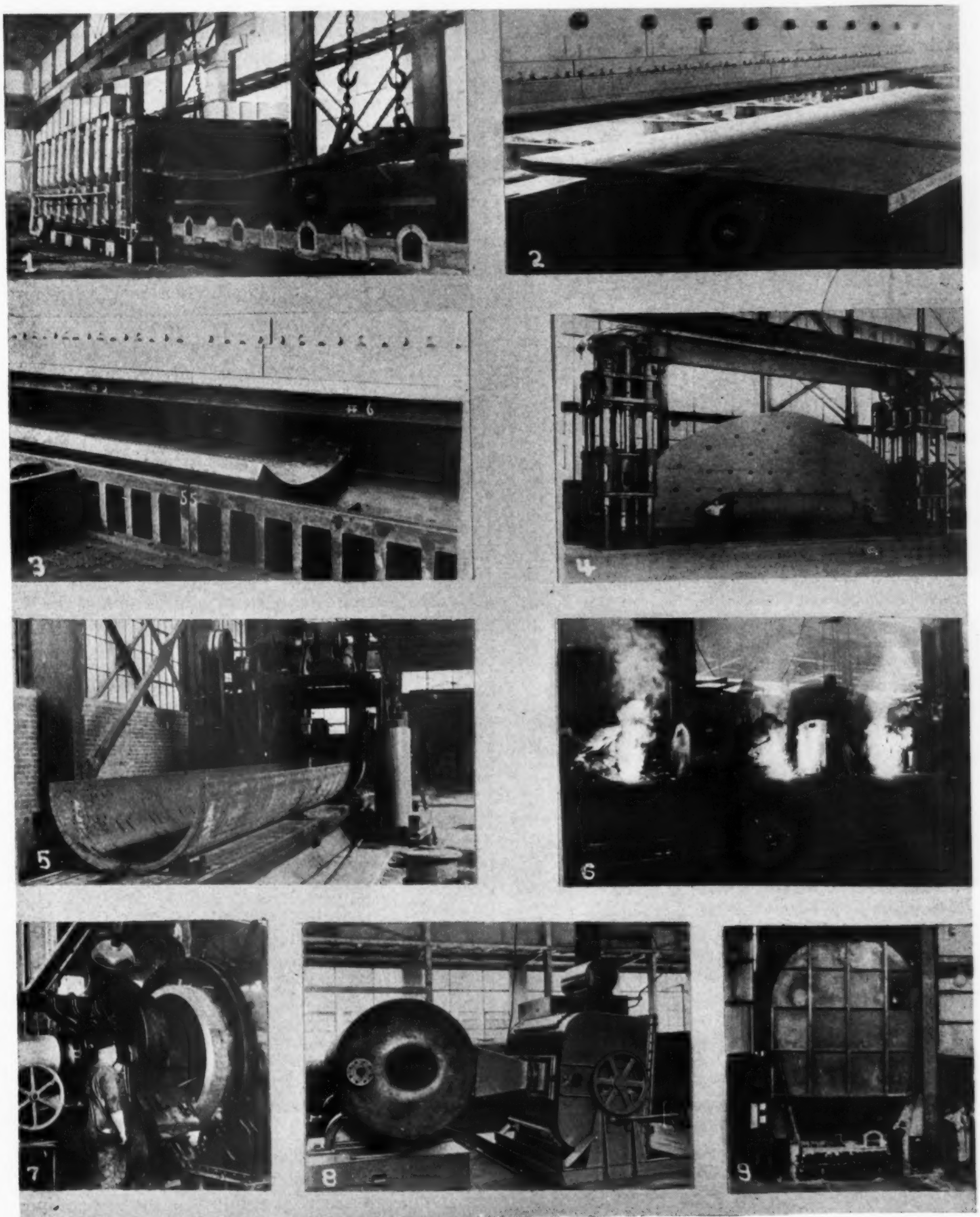
The next operations consist of chipping and grinding the longitudinal seams, rounding-up, if necessary, and stress-relieving if necessary to secure proper roundness.

Following this, X-rays are made of the longitudinal seams. If any defects are discovered, they are cut out, and the seams re-welded. X-rays of the repairs are made.

While the foregoing work is being done on the shell plates, the heads are being prepared by another group. The next operation is the turning-down of the shell ends to fit the heads (see Fig. 7) and the preparation of the welding groove for receiving the heads, which are fitted to the shells and welded. The layer-out then checks the location of all nozzles, brackets and other attachments to be welded prior to stress-relieving. These are then welded in place, and all welds chipped and ground. After this, the girth seams are X-rayed, as indicated by Fig. 8. The layer-out then locates hanger grooves and seats for saddles, which are machined. The drum is now ready for the stress-relieving furnace, shown in Fig. 9. Following this stress-relieving operation, the drums are sand-blasted or steel-shot, if Apexior or other coating material is later required, and the manhole plates are carefully fitted.

The drum is now ready for hydrostatic test which is witnessed not only by our own inspectors but by authorized inspectors. After this test, the drum is mounted on a large face-plate; the theoretical center line is determined by special apparatus; and the layer-out locates all tube holes which, in our case, are located by the angulation method so that tube holes and openings point directly toward the theoretical center line. Tube holes are drilled with large radial drills, using special jigs to insure exact locations and close tolerances. This opera-

* From a paper presented at the Twelfth General Meeting of The National Board of Boiler and Pressure Vessel Inspectors.



Steps in the construction of a high-pressure fusion-welded boiler drum

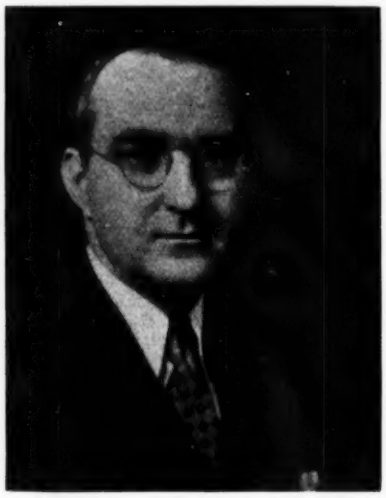
tion is shown in Fig. 10. Tube holes are grooved, and counterbored where necessary, all special openings and machine operations are carried on, and the nozzles are refaced where they have become slightly out of line during stress-relieving or other operations. Tube holes are then dressed.

The final operation consists of fitting into the drum, all the various internals, such as steam washers, baffles, steam-drying equipment and other fittings.

When these operations are completed the drum is given its final inspection. All measurements and locations are checked, such match markings as are required for erection are applied, and the drum is given its final inspection and stamping by an authorized inspector. It is now ready for greasing the machined parts, capping tube holes, painting, capping the nozzles and shipment.

New President of N. I. A. A.

Charles McDonough, Advertising Manager of Combustion Engineering Company and Vice President of Combustion Publishing Company, was elected President of the National Industrial Advertisers Association at the final session of its 17th Annual Convention, held in New York City, September 20 to 22. For the past three years Mr. McDonough has been a vice president of the N.I.A.A. and has devoted much time to a study of the public relations problems of industry. He believes that one of the major tasks now facing the N. I. A. A. is to improve



the professional status of the advertising managers in order that management may be convinced of their ability to assume greater responsibility in the work of increasing industry's selling efficiency and potential profit.

The N. I. A. A. is an organization composed of those engaged in directing the advertising and marketing analyses of the principal industrial manufacturing companies and has twenty local chapters over the United States and two in Canada.

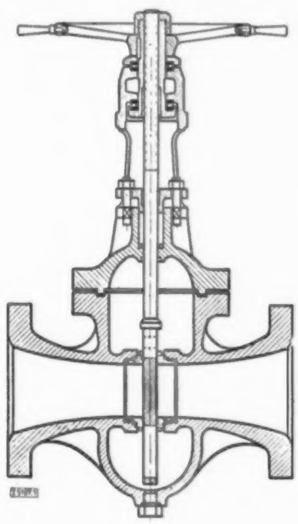
Other officers elected at the closing session were: Vice Presidents—R. P. Dodds, Truscon Steel Co.; W. D. Murphy, Sloan Valve Co.; H. V. Mercready, Magnus Chemical Co.; E. J. Goss, The Koehring Co.; Terry Mitchell, Frick Co.; and H. S. Van Scoyoc, Canada Cement Co. Secretary-Treasurer—R. L. Towne, Surface Combustion.

STEAM ENGINEERING ABROAD

As reported in the foreign technical press

High-Pressure Gate Valve

In *Zeitschrift des Vereines deutscher Ingenieure* there is described a valve for high steam pressures and temperatures which is self-sealing and of very simple construction, as shown in the accompanying sketch.



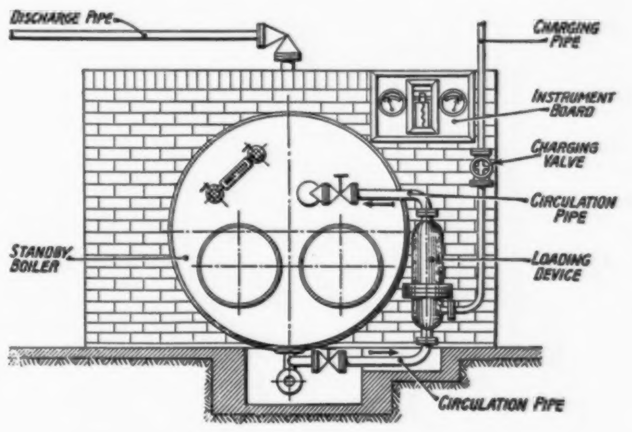
Section through valve

The closure is accomplished by a gate which is raised and lowered as usual in a gate valve by a spindle. This gate is suspended between seat rings with a clearance of only 0.01575 in. and upon closure is pressed against a seat ring by the steam pressure. The clearance is so chosen that the gate will not seize in the seat rings with rising temperature and yet is so small that foreign matter cannot crowd in. The gate and the seat rings are hardened by nitriting to guard against wear and are ground accurately flat and mirror smooth. Due to the loose connection between the spindle and the gate, a slight movement is available in the direction of the centerline of the tube, as well as departure from the axis of the spindle, if the seat ring surfaces are not exactly parallel to one another or to the axis of the spindle. The diameter of thè opening at the gate is 0.6 of the tube diameter and is provided with easy smooth approaches.

During a test, a 10.8-in. gate having a seat ring opening of 7.1 in. was subjected to a steam pressure of 938 lb gage at a temperature of 896 F. The load on the gate was about 37,000 lb and the surface pressure 2420 lb per sq in. for a seat ring face width of 0.63 in. Fifteen turns sufficed to open and close the gate with a lift of 7.7 in. and a pitch of the spindle of 0.5 in. With full steam pressure on one side of the gate it was found that the coefficient of friction between the sealing surfaces was only 0.09 instead of 0.12 as calculated. The force required at the handwheel periphery of 92.7 lb did away with the necessity of an unloading device such as a bypass. There is no spindle pressure required for seating the gate as is usual. The valve may be used in any position and its weight is relatively small.

Steam Storage System

The Power and Works Engineer (London) of September describes an inexpensive system of steam storage introduced by British Boiler Accessories Ltd. whereby old cylindrical or standby boilers can be utilized to increase the reserve of hot water ready to flash into steam on the occurrence of peak loads. The equipment comprises an outer mixing chamber, or loading device, into which live steam is introduced and which is connected with the boiler at the blowdown and at the water line, thereby inducing circulation of the water within the boiler. The mixing chamber takes any surplus steam when the pressure is high and thus prevents blowing off of the main boilers; or smaller quantities of steam can be introduced from time to time in order to keep the volume of water in the standby vessel up to saturation temperature. Subsequently, at periods of heavy demand steam can be drawn from the standby vessel to an extent depending upon the permissible drop in steam pressure.



Sketch showing attachment of loading device

The arrangement as indicated in the sketch here shown is hand controlled and provided with an instrument panel having pressure gages and a recorder, but automatic control can be applied if desired.

Burning Cork Waste

E. T. Ellis, in an article on "Using Industrial Residues for Power Generation," which appears in the August issue of *Industrial Power and Fuel Economist* (London), refers, among other things, to the burning of cork waste. This, he says, is best handled as a boiler fuel by first being gasified. Briquetting is usually necessary as the first step in the process. This is done by molding the

cork waste into bricks or blocks, using a cheap glue as the binding agent. When dry and hard the bricks are packed into retorts which can be tightly closed and all possible air withdrawn. The safety valves are then set and the temperature raised rapidly. Under these conditions much gas comes off. The tarry constituents of the gas are removed by rapid cooling; carbon dioxide is taken out by passing through towers filled with lime; and the gas is burned under the boilers by means of special jets.

Steam Turbine Studies Based on Water Turbine Analogy

In the *VDI Zeitschrift* for May 13, 1939, E. Sörensen discusses the unit diagram for water turbines and develops a similar unit diagram for steam turbines.

In water turbine studies the unit turbine is considered as having a runner diameter of one meter and operating under a head of one meter. The revolutions per minute, n', and the volume of water, Q', in cubic meters per second, flowing through it, may be calculated from a geometrically similar turbine having a diameter of D meters, revolutions per minute, n, and a water volume, Q at a head of H meters. Then, $n' = nD/\sqrt{H}$ and $Q' = Q/D^2\sqrt{H}$.

The unit diagram is determined from carefully planned measurements on models and provides a survey of the performance of a turbine under various operating conditions much more comprehensively than may be obtained by calculations. Such a diagram is shown in Fig. 1.

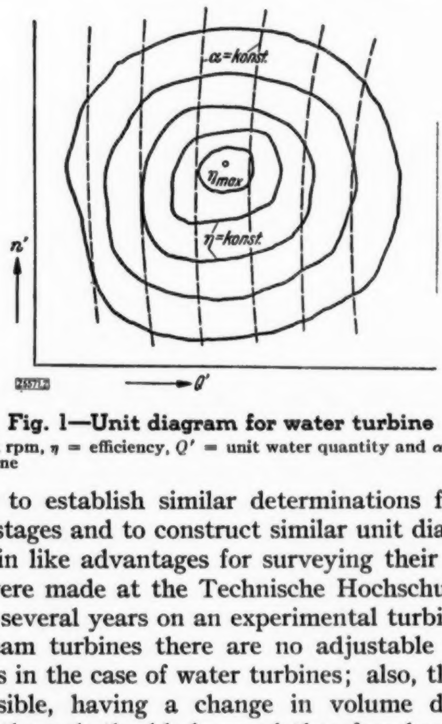


Fig. 1—Unit diagram for water turbine

n' = unit rpm, η = efficiency, Q' = unit water quantity and α = angle of directing vane

Trials to establish similar determinations for steam turbine stages and to construct similar unit diagrams so as to gain like advantages for surveying their performances, were made at the Technische Hochschule, Dresden, for several years on an experimental turbine.

In steam turbines there are no adjustable directing vanes, as in the case of water turbines; also, the fluid is compressible, having a change in volume during its passage through the blades, and therefore has no comparable hydraulic operating conditions. The change in volume in steam turbines, however, becomes similar to the variable settings of the directing vanes in water turbines and the author discusses this similarity.

For the unit steam turbine the wheel diameter through the blades is chosen as one meter and the heat drop through it as one kilogram-calorie per kilogram. A difficulty arises in that a drop of one kg-cal per kg for steam

at a given state has definite volumetric relations and the unit steam turbine cannot work under the desired volumetric conditions if the steam state is fixed. This difficulty is avoided by assuming within the steam turbine, a steam or gas which has the desired volumetric relations with a drop of one kg-cal per kg and designating it as hydraulically similar, whether or not such a gas exists.

In practice the trial was conducted at such a heat drop, h, where just the desired volumetric relations occurred and the experimental results were calculated to a drop of one kg-cal per kg without changing the volumetric relations.

The changing volume in a steam turbine stage is similar to that in a single nozzle with a suitably chosen exit area, F. By converting the adiabatic drop through the nozzle into head, H, in meters, by the mechanical equivalent of heat, A, ($h = AH$), there are found the exit velocity, C_a, the volume of the steam at the entrance and exit ends of the nozzle (V_e and V_a, respectively); and, when knowing the pressures P_e and P_a and specific weights γ_e and γ_a of the steam at the respective ends, the weight, G, of the steam flowing can also be found.

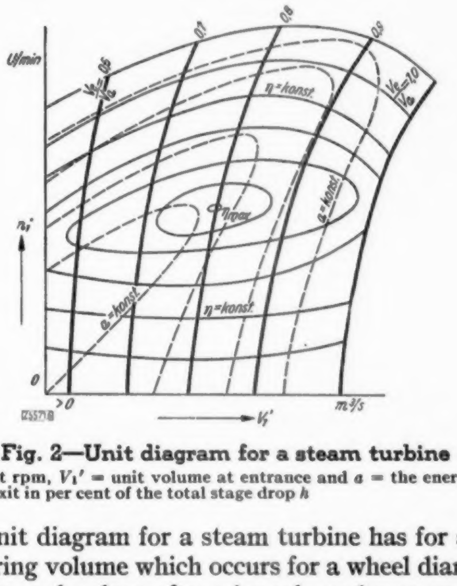


Fig. 2—Unit diagram for a steam turbine

n_1' = unit rpm, V_1' = unit volume at entrance and a = the energy of velocity at the exit in per cent of the total stage drop h

The unit diagram for a steam turbine has for abscissa the entering volume which occurs for a wheel diameter of one meter and a drop of one kg-cal per kg or one meter. Since the flow conditions are dependent on the relation of inlet and exit volumes of the steam through the stage, the ratio of these volumes is included in the unit diagram. These lines become the equivalent of the lines of constant directing vane openings (α, Fig. 1) in the water turbine diagram. Fig. 2 shows a unit diagram for a steam turbine and is very similar to that of a water turbine.[1]

The diagram becomes of value only when constructed exclusively from test measurements, since the uncertain assumptions of losses within the steam turbine exclude accurate calculations. It provides a reliable survey of every possible operating condition of the stage in question just as was heretofore only the case for water turbines. Consequently, there is provided a much more secure foundation for steam turbine calculations and the investigation of the performance of a steam turbine when departing from operating conditions may be approached with less difficulty. The author then discusses applications of the unit diagram to steam turbines.

[1] Similar to the case of the water turbine the revolutions per minute of the unit turbine, $n^1 = nD/\sqrt{h}$, and the entrance volume $V_1 = V_e/(D^2\sqrt{h})$.

Fly Ash and Dust Collection

In a paper by Dr. Friedrich Münzinger, well-known German engineer, which is reviewed in *The Steam Engineer* of September, the author discusses the economics of fly ash and dust arrestors versus stack heights. Observing that the lower the stack the higher must be the efficiency of collection, he points out that the cost of electrostatic arrestors rises rapidly if higher than about 90 per cent precipitation is required. The extra cost of a 459-ft stack, serving several boilers, over one of 164 ft, may be more than offset by the lower cost of a mechanical separator having 80 per cent efficiency.

Taking the case of a boiler plant generating a million pounds of steam per hour and equipped with efficient arrestors for coarser dust, Dr. Münzinger suggests that from 0.125 to 0.4 ton of ash per hour may be discharged in residential districts and from 1 to 3 tons per hour in industrial areas. On this basis, the percentage of recovery of coarse particles required inside the plant is:

Ash Content of Coal, Per Cent	Residential Districts, Per Cent	Industrial Districts, Per Cent
10	85 to 95	40 to 75
30	98 to 99.5	90 to 97

Thus at large plants burning coal of high ash content, high stacks are essential as the only alternative to dust nuisance. The provision of such stacks without violating aesthetic principles is largely a matter of collaboration between the architects and the engineers, and in some cases such stacks may be of substantial assistance to the former in securing a balance between the main building and such appendages as coal-handling equipment, cooling towers and outdoor switchgear.

REVIEW OF NEW BOOKS

Any of the books reviewed on this page may be secured from Combustion Publishing Company, Inc., 200 Madison Ave., New York

Engineering Materials

By Alfred H. White

In these days of rapid advances in engineering practice much depends on the selection of materials suitable to the conditions imposed. Through research much has been learned concerning the properties and limitations of widely used materials and many new products have been brought out to meet new conditions. Professor White, who is a well-known authority on this subject, brings the reader up to date on what has been going on and what is available. Written primarily as a textbook for engineering students, the book should also serve as a useful reference for practicing engineers and designers.

Among the subjects covered are iron and its alloys with carbon, heat treatment of iron-carbon alloys, the manufacture of iron and iron-carbon alloys, the manufacture of steel and the influence of its chemical composition, the properties of plain carbon steel, gray cast irons and malleable castings, steels with one, two or more alloying constituents, various other metals and their alloys, corrosion and its protection, rock products, clays and silicates, cements, fuels and combustion, water and its treatment, organic preservative materials, plastics and related products.

There are 547 pages, 6 × 9 in., with 200 illustrations; price $4.50.

Stoker Handbook

By H. D. Airesman

Written as a practical text for those who design, sell, install and operate small industrial or domestic stokers, the book presents the fundamentals of combustion and heating, discusses different fuels and their characteristics, shows how to conduct gas analyses and make tests, how to estimate coal consumption, to determine the size of stoker required and gives helpful information on the operation and care of stokers. There are 200 pages, illustrated and containing numerous tables. The price of the book is $3.

Steam and Hot Water Fittings

By William T. Walters

This very practical book explains and shows by means of various sketches and tables how properly to select, design and install such systems to secure good heating. The essential tools are illustrated and their uses explained. Intended for students, apprentices, steamfitters and designers, the text should also prove very useful to many engineers in checking their own domestic heating systems. There are 184 pages, 182 illustrations and numerous tables. Price $2.

Heating and Air Conditioning Fifth Edition

By J. R. Allen and J. H. Walker

Earlier editions of this book represented the joint work of the late John R. Allen, formerly President of the American Society of Heating and Ventilating Engineers, and James H. Walker, Superintendent of Central Heating, The Detroit Edison Company. In the present edition Mr. Walker has carried on in order to bring the book abreast of present practice in the art of heating and air conditioning, particularly the latter which has undergone remarkable development in the last few years. Much material has been added on controls, air distribution, cooling coil performance and cooling load calculations. Also, many new problems have been added.

The book is intended primarily as a treatise for use in engineering schools but it is also a valuable reference for practicing engineers in that it contains much data on performance, useful charts and suggestions that should prove helpful in the selection of equipment. All of the principal systems are explained and their applications discussed. The text is practical and employs mathematics only to a limited extent. It covers nearly 600 pages, has 300 illustrations and an appendix containing numerous tables. The price is $4.50.

Internal Combustion Engines

By Lester C. Lichty

As a 600-page treatise on internal-combustion fundamentals, fuels, engine design and performance, the book carries the reader further than the ground generally covered in an undergraduate course on the subject, and therefore has a broader appeal than the usual textbook. In this, the fifth edition, the analyses of combustion and other thermodynamic processes have been simplified and the chapters on fuels, detonation and fuel injection have been completely rewritten and amplified in the light of recent knowledge gained through research and development. The theory of lubrication is given greater attention and more information on materials of construction is included. Its price is $4.50.

Manual of Ordinances and Requirements

The 1939 edition of this publication of the Smoke Prevention Association, in addition to containing papers on air pollution, smoke elimination and fuel combustion, as presented before the Thirty-Third Annual Convention of that association, also includes a compilation of the smoke ordinances of eighty principal cities in the United States as well as other data pertaining thereto. Other useful information and charts dealing with fuels and their combustion are included. The manual, in paper cover, contains 172 pages and is priced at 50 cents.

Carbonization of Colorado Coals

The Denver region coal field, covering an area of approximately 7640 sq miles, produces over $2^{1}/_{2}$ million tons of sub-bituminous coal per year. These coals average 22 per cent moisture and 9600 Btu per lb as mined. U. S. Bureau of Mines, Report of Investigations No. 3457, contains information on friability and slacking characteristics of these coals, as well as the results of a series of small-scale, low-temperature carbonization tests.

These assay tests at 500 and 600 C were made in a gas-heated 50-gram cast-aluminum retort with the coal sample ground to pass through a 20 mesh, the retort being heated from room temperature to the carbonizing temperature in one hour and maintained at that for an additional hour. Tests at 700 C were made on 35-gram samples in an electrically heated steel retort for two hours.

The resulting products were a reactive char, amounting to about one-half the weight of the original sample and having a heating value of 13,500 Btu per lb; 3 to 9 per cent tar oils; 26 to 31 per cent condensable water; and 450 to 1430 Btu in gas per pound of coal.

In connection with the article by C. B. McBride on "Dust Collection Tests at New Power Plant of the Industrial Rayon Corporation," which appeared in the September issue, attention has been called to the considerable variation in dust actually caught in the various seven-hour runs. This was due to a large variation in the ash in the coal which had been caused by a fire in the coal pile previous to the tests, and also to the exact periods when soot blowing occurred.

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